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STRUCTURAL ANALYSIS OF A 1 kW DARRIEUS TURBINE SPOKE

Federico Belloni[1], Gabriele Bedon[1], Marco Raciti Castelli[1], Uwe Schmidt Paulsen[2], Ernesto Benini[1]
[1]University of Padua, [2]DTU Wind Energy

Abstract

A structural study of a 1 kW Darrieus turbine spoke was performed in order to study stress distribution on the piece and make it more light. The VAWT turbine, originally intended for urban operation, is provided with 3 blades and 6 spokes. Since turbine initial tests showed relevant balancing issues, the main analysis target was to reduce the rotor weight. A detailed analysis of the involved forces (both inertial and aerodynamic) was performed in order to evaluate the most significant loads affecting the structure. A finite element approach was adopted to simplify the structure composed by one blade and two spokes. A first finite element model was implemented to extract force reactions at the spoke tip. Reactions were then used in a second more refined and experimentally validated finite element model, representing only the spoke, in order to evaluate stress distribution. In this model, the spoke was considered rotating at the maximum admitted rotational speed, since centrifugal forces were observed to be much more remarkable than others loads. Original steel configuration and different architectures with shaped holes made along the spoke were simulated, but stress value was found to exceed inevitably yield stress at most critical cross section. Therefore, the final spoke was designed in aluminum. This implied a remarkable weight reduction as well as a notable stress value reduction.

System of forces analysis

The first analysis step deals with system of forces involved and helps to understand the spoke mechanical behaviour, in order to compare the various contributions acting on the component. They mainly consist of aerodynamic forces and centrifugal ones. The most critical situation, simulated within the Blade Elements Method (BE-M) used to design the turbine blade [1] , was taken as reference at maximum wind speed (25 m/s) and rotational speed (300 rpm), and a comparison between the two force contributions is presented in Fig.1. A strong predominance of centrifugal forces can be easily noticed [2].

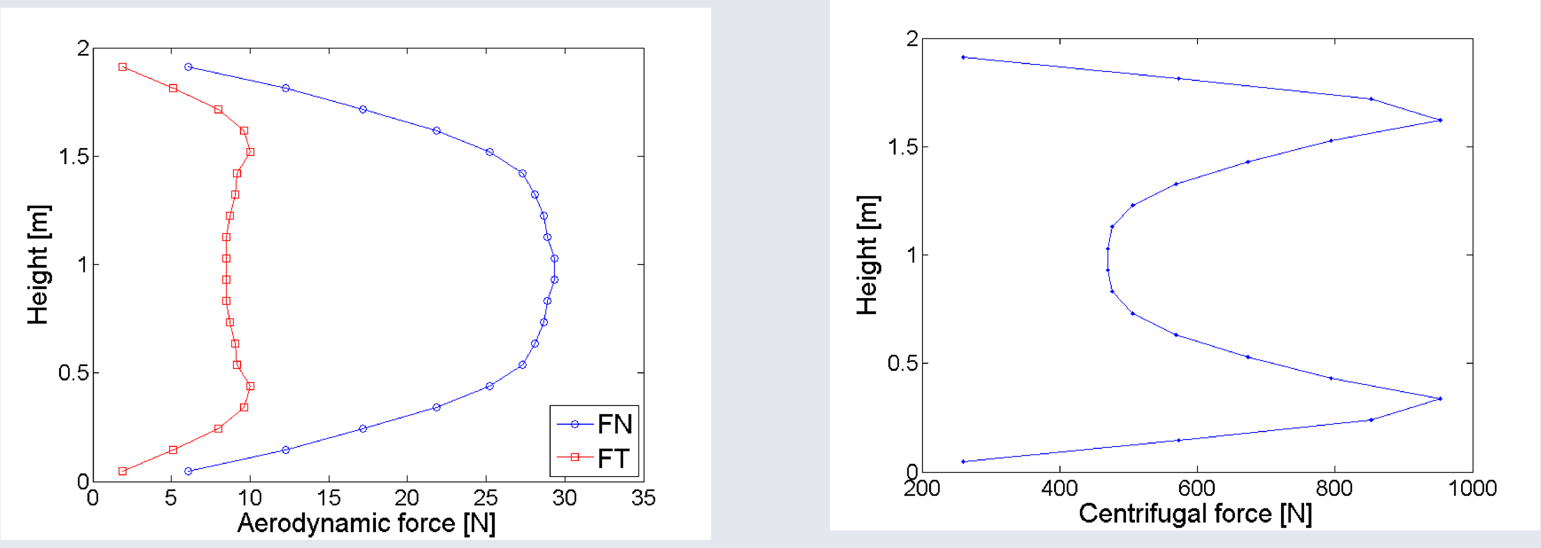

Fig. 1: Comparison between aerodynamic normal (FN) and tangential (FT) forces and centrifugal ones, as a function of turbine height, for 25 m/s and 300 rpm.

Nevertheless, aerodynamic force fluctuations have to be considered since they are a potential cause of fatigue damages on the spoke. The load ratio R between involved forces was investigated for several combinations of wind speeds and rotational speed and it was found to exceed 0.7. Then, knowing that this analysis is preformed on a turbine prototype and that the final design is not necessarily consistent with the spoke configurations here investigated, a static analysis approach was carried out.

FEM analysis

A finite element structure was developed in Strand7. The statically indeterminate structure, represented in Fig.2, was defined through a particular amount of beam elements. Each of them was set up with particular material properties and geometric dimensions. The chosen model was linear static. ANSYS Mechanical was then used to develop a more refined and precise analysis of the problem.

Several structural tests (see Fig.3) were performed on two different spokes, the original one manufactured in steel and a second one in aluminum, in order to validate the applied FEM model. Moreover an analytical model was developed. A linear bending moment distribution was assumed along the spoke, modelled as a cantilever beam with constant cross section area.

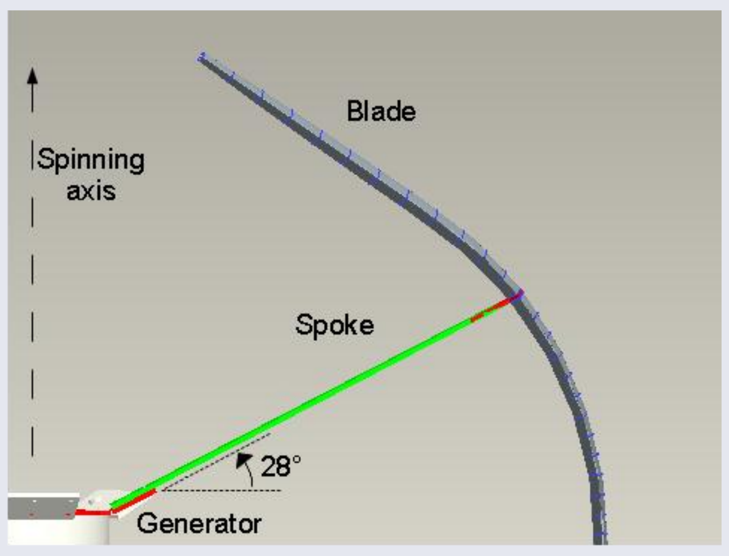

Fig. 2: The system composed of upper half turbine blade and one spoke.

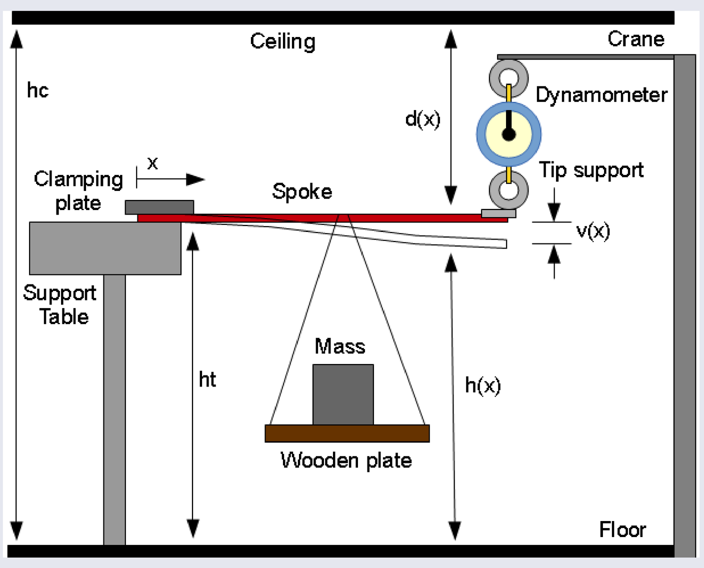

Fig. 3: Sketch representing spoke test equipment.

FEM Results

- **Spoke structural tests**

Figure 4 show a comparison of test measurements, simulation results and linear models for steel spoke and aluminum one respectively. Linear model approximated properly ANSYS simulations, but values found by these were found to be slightly underestimated in respect to experimental data.

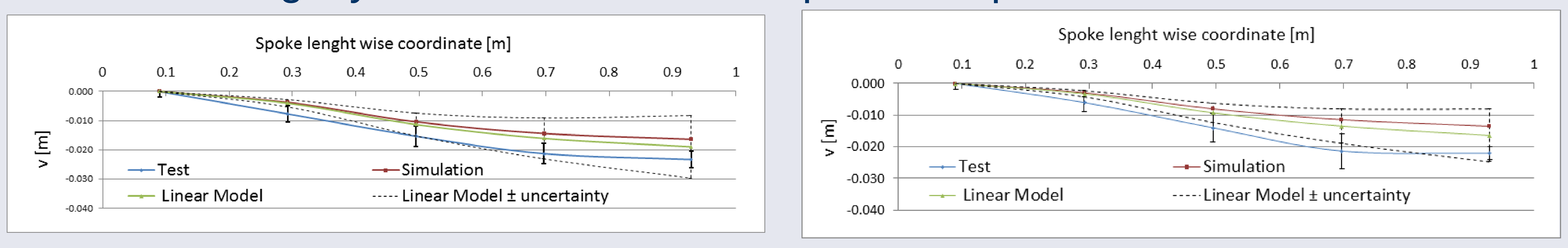

Fig. 4: Comparison between measured vertical displacements (v) and simulated ones. The left graphs is related to the steel spoke, while the one on the right to the aluminium one.

- **Spoke different designs**

Several spoke designs were analysed and the most critical region for stress distribution was detected at the hub spoke connection. Simulation results, described in Fig.5, showed that in the original spoke in steel, 10 mm thick , stress at the clamped cross section reached values very close to material yield stress. A thickness reduction to 8 mm did not help to reduce stress value. Then a different spoke design, characterized by several triangular shaped holes, was studied, as it is shown in Fig.6. However, yield stress is still reached in the hub region where, moreover, stress concentrations were observed at hole corners.

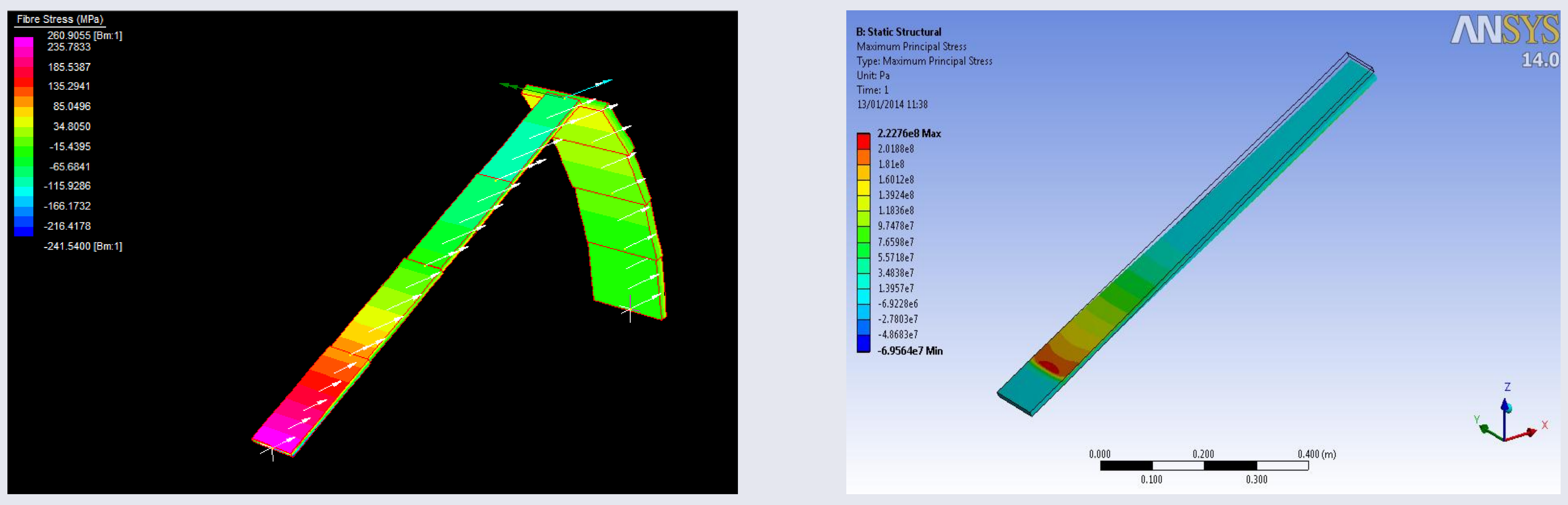

Fig. 5: Original spoke configuration: maximum principal stress from Strand7 (left) and ANSYS (right) simulations.

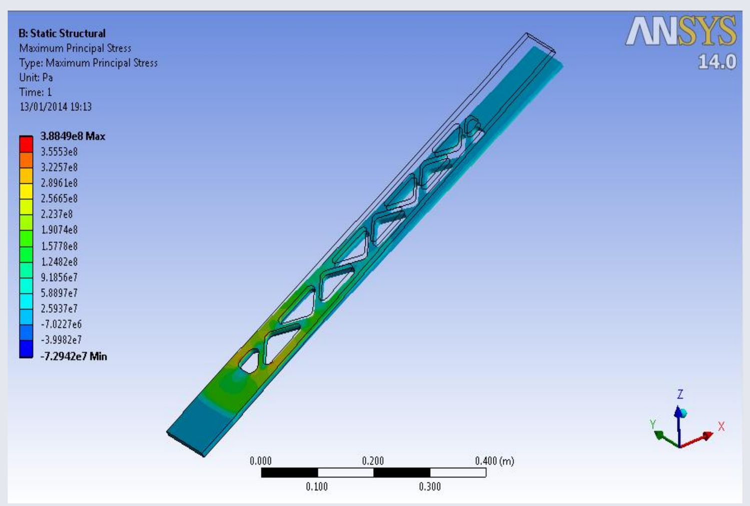

Fig. 6: Spoke configuration with triangular shaped holes: maximum principal stress from ANSYS simulations

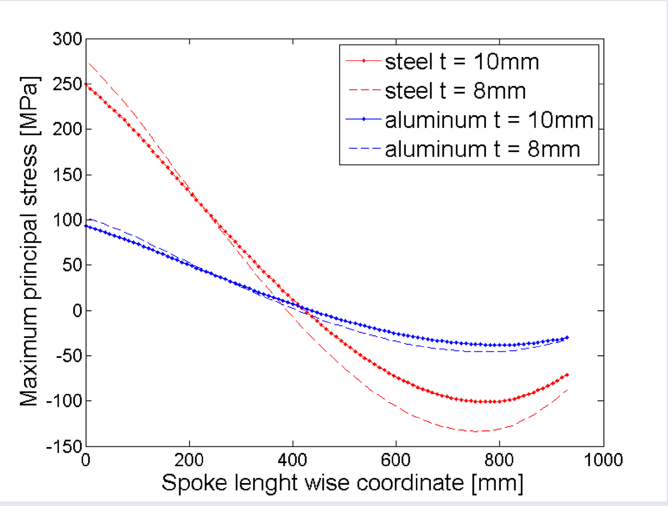

Fig. 7: Comparison of principal direction stress distribution between spoke proposed designs.

As an alternative, an aluminum spoke configuration was analysed. Centrifugal forces were shown to decrease significantly to about one third of the value in the original steel spoke. This involved a notable reduction in bending moment and stress values, as it can be seen in Fig.7. In the final design the aluminum 10 mm thick spoke was chosen to replace the original one on the turbine.

Conclusions

The conducted study has shown that, for a small Darrieus Turbine, the spoke is one of the mostly stressed component during turbine operation. Therefore, an accurate study of its behaviour is definitely important within a structural study of the rotor. The comparison between the forces involved in a working VAWT has shown how aerodynamic forces are negligible if compared with centrifugal forces. The FEM results were, in conjunction with the experimental tests, found more reliable in modelling the original steel configuration and the different setups with various shaped holes. A final aluminum spoke was chosen, obtaining a stress reduction on the component and, on the other hand, a 66% weight reduction for each spoke, corresponding to 25% of the whole turbine weight.

References

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